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# A Decision Support System for Sustainable Urban Development: The Integrated Land Use and Transportation Indexing Model

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**Abstract**
Broad definition of sustainable development at the early stage of its introduction has caused confusion and hesitation among local authorities and planning professionals. The main difficulties experienced are how to employ loosely-defined principles of sustainable development in setting policies and projects and to gauge the efficiencies of these policies in terms of reaching the designated sustainability goals. The question of how this theory/rhetoric-practice gap could be filled will be the theme of this study. One of the widely employed sustainability accounting approach by governmental organisations, triple bottom line, and applicability of this approach to sustainable urban development policies will be examined. When incorporating triple bottom line considerations with the environmental impact assessment techniques, the framework of GIS-based decision support system that helps decision-makers in selecting policy options according to the economic, environmental and social impacts will be introduced. In order to embrace sustainable urban development policy considerations, relationship between urban form, travel pattern and socio-economic attributes should be clarified. This clarification associated with other input decision support systems will picture holistic state of the urban setting in terms of sustainability. In this study, grid-based indexing methodology will be employed to visualise degree of compatibility of selected scenarios with designated sustainable urban future. In addition, this tool will provide valuable knowledge about spatial dimension of the sustainable development. It will also give fine details about possible impacts of urban development proposals by employing disaggregated spatial data analysis (e.g. land-use, transportation, urban services, population density, pollution, etc.). Visualisation capacity of this tool will help decision makers and other stakeholders compare and select alternatives of future urban developments.

**Keyword:** Sustainable urban development, planning decision support systems, GIS, spatial indexing

## Introduction

Sustainability concept and its applicability to real settings has been one of the most discussed issues in the literature. As fast urbanisation and growing population of cities is considered, implications of changing life style related sustainability problems and how these are remedied could be considered as the most pressing subject of the urban planning profession. Complex nature of both cities and politics forces urban planners to analysis contemporary problems of the cities more carefully and to produce more effective policy recommendations. Analysis and policy determination of these issues need a framework, in particular when considering development strategies of the cities. In this respect, emerging sustainable urban development (SUD) concept could be tied to considerations and procedures of aforementioned generation of policy recommendation responsibility of urban planners, but initially problems should be analysed due to its effects on urban sustainability. In the literature, most of the SUD issues are grouped according to its relationship with the urban form and transportation interaction. Starting from revealing this interdependence between urban form and travel pattern of the individuals/households, it could be possible to define causes of and intervention options to SUD problems. This reasoning is the basis of this study. After identifications of the problems and their relationship with the selected urban setting, determination of policy development will be discussed. In order to avoid replacing

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decision maker, policy development process will be scrutinised together with planning decision support system framework. It will give opportunity to decision maker in changing decision parameters or relative weights, and testing sensitivity of the interventions designated. This framework will be employed by the help of GIS technology. Spatial indexing method will be used to make analysis and to produce relatively fine detailed model output. Unit of analysis of 25mx25m square-shaped-area is selected according to computational easiness, provision of detailed outcome and lucid visualisation. This spatial indexing model is constituted five modules corresponding to processes explained before. Initially, both spatial and aspatial data will be converted to grid layers via data collection and manipulation module. Then, these layers will be analysed and parametric relationship between them will be calculated. Via indexing module, sustainable index set will be converted to composite sustainability index. At the last phase, evaluation and policy module will evaluate current state and future scenarios to give insight about policy options open to decision maker. Decision maker could identify SUD problems and propose new policies affecting model inputs for next iteration. Policy options will be used as model input in a circular way to iterate model to forecast effects of modified policies. This construct will provide clear picture of how urban form and transportation policies could change total sustainability performance of the urban setting.

## Land-use and transportation in the context sustainable urban development

Recently, great deal of world population lives in cities and urbanisation trend in both developed and developing countries is following an upward trajectory. Living in the urban setting changes people's life styles substantially, especially their consumption pattern. Considered together with the life style and consumption pattern of people and current sustainability problems, making urban development process more sustainable by spatial policies and projects has critical importance. That is to say, when considered with rapid increase in urban population in the future, even small changes in structure of urban system affecting citizens and firms daily life and operations could provide considerable benefits or vice versa. So, urban planning as respective endeavour to arrange urban systems has crucial role in overall sustainability performance. The planning system, and specifically development plans, is a key arena within which economic, social and environmental issues come together with respect to the spatial dimensions of management of environmental change. It is this interpenetration of environmental issues with economic and social issues which is the key contemporary challenge for the new environmental agenda (Healey et al., 1993). Thus, the planning system should manage this challenge rationally. Otherwise, the agenda of environmental issues may be constantly challenged by the expediency of political short-termism as it affects economic development projects (Healey et al., 1993).

There are four complementary parts constituting the general considerations of SUD for urban planning: urban form, transportation, infrastructure and environment. In SUD, environment could be placed at the centre of framework and others could be explained by referencing to their effect on it or to how they affected from the changes in environment. There is also cross-relationship between three other factors. However, bulk of the literature is concerned with the interdependence between urban form and transportation and effect of this interdependence on environment and SUD concerns. These concerns are low density housing, separate urban land-uses, decrease in accessibility and quality of urban services, increasing car dependence and non-renewable energy usage, pollution, traffic congestion, low public transportation patronage, and increasing number of fatalities and accidents on roads. Additionally, equity dimension of the urban form and transportation relationship is another important subject that could be discussed as to framework of social exclusion and segregation, low accessibility to urban services and increasing cost of urban services. Effects of climate change have carried the importance of urban infrastructure, particularly water related infrastructure, into the debate, until recently.

Dynamic interrelationship between current mobility pattern and urban form is examined in various urban areas, and researches have showed that car dependency is the primary driver of the urban sprawl. Consequent fragmented/sprawled urban form, in return, increases the need for car transport and car dependency (Newman et al., 1999). Comparison among various cities from various countries has revealed some planning objectives that might diminish car dependency. Increasing urban density, planning cities by allowing mixed use, designing transportation system in accordance with public transportation, cycling and walking initiation, locating new development near the existing urban areas and making settlement larger in size are considered as good policies in reaching sustainable urban transportation goals (Banister, 1997; Banister et al., 2000; Kenworthy et al., 1996; Litman et al., 2006; Low et al., 2003; Newman, 2006; Shore, 2006). These attributes could be found mostly in European cities (Greene et al., 1997; Newman et al., 1999) and some of the developing countries (Hensher, 1998). However, opponents of high density claimed that this is not the urban form that makes European cities relatively more sustainable but traditional city form, high public transportation patronage, high fuel prices and stringent tax policies force people to travel less with cars (Breheny, 1995). They also added that urban containment and consolidation could result in increase in land prices and real estate and this strengthens the suburbanisation trend that stimulus car mobility (Breheny, 1995; Burton, 2000; Gordon et al., 1997). Furthermore, some argue that because of the capacity limits of the infrastructure in urban areas, increasing density would not be possible or be costly, and high density is not desired for many people and degrades quality of life in urban areas (Low et al., 2003). Conceptualisation of aforementioned good policies have revealed various urban planning movements, such as smart growth, new urbanism, transit oriented development, decentralised concentration. Among these, decentralised concentration (Holden, 2004) stands out with its adaptability to current urban patterns and changing movement demand.

Whether new direction of sustainable transportation policies should be focused only on mobility and technology issues or would they also consider developing accessibility of citizens to urban opportunities and restoration of transportation disadvantages in order to raise social capital (Banister, 2000; Burton, 2000; Moriarty, 2002; Roseland, 2000) is another dimension of SUD. These questions underline social sustainability perspective. It is sustainability policies should take into account social considerations together with the environmental and economic sustainability issues (Roseland, 2000). These also coincide with efficiency vs. equity arguments of market and governmental regulations. These arguments refer that policies which increase cost of the pollution and travel to effectuate sustainable transportation goals should not be only instruments but some other compensating measures, such as decreasing labour tax that cover increased transportation cost of low-income people (Roseland, 2000; Schade et al., 2000), subsidising public transportation and other low cost transportation infrastructure, such as cycling and walking, particularly in the areas where transport disadvantages have occurred should be considered (Banister, 2000; Black et al., 2002; Polzin, 1999). These measures rectify poor definition that equates mobility to accessibility to clear one

(Greene et al., 1997) to access public services and other urban land uses with various transportation means (Yigitcanlar et al., 2008). In summary, a socially just transport system provides a fair distribution of transport services and equal access to employment, housing, education, health services and recreation (Gold Coast City Council, 1998).

Apart from urban transportation infrastructure, sanitation, sewage and waste disposal infrastructure are also included into SUD policies. In recent decades, dramatic effects of climate change are experienced in both urban and rural area. Particularly, changes in rainfall have dramatically affected agricultural production and clean water resources. In order to avoid from negative effects of climate change, governments have started to apply some protective measures, in particular precautions focusing on protection and management of water resource. In the UK and Australia, Water Sensitive Urban Design (WSUD) has employed for this purpose. In brief, WSUD could be defined as the integration of management of the urban water cycle with urban planning and design. WSUD embraces necessary design principles of water consumption, water recycling, waste minimisation and environmental protection (Water et al., 2005). From the sustainability perspective, design of water related infrastructure by considering transportation infrastructure has great importance, because transportation related pollution one of the major source of water pollution. As stormwater runoff considered, roads are the non-point-type source of water pollution. In order to maintain safety and health of water resources and water habitats, externalities of transportation should be minimised with SUD policies.

Aforementioned considerations related to SUD are originated from the definition of sustainable development. After sustainability definition of Brundtland, consequent debates point out that economic interests and environmental considerations are not the opposite or conflicting sides of development discourse and in order to secure intergenerational equity, these sides should meet agreed upon mutual interests. In other words, it is possible to form alternative economic growth policies that sustain the environmental capacities of future generations (Healey et al., 1993) and enhance intra-generational equity. These considerations are also subject of a new sustainability framework called as triple bottom line approach (TBL). First appeared at the corporate level, TBL could be defined as:

> The triple bottom line focuses corporations not just on the economic value they add, but also on the environmental and social value they add – and destroy. At its narrowest, the term 'triple bottom line' is used as a framework for measuring and reporting corporate performance against economic, social and environmental parameters (Elkington, 1980; Suggett et al., 2002).

In particular local governmental level, three tiers of TBL (economic, social and environmental development) have been tried to being included into the planning process to develop SUD policies. There exist some explanatory/regulatory endeavours in this direction; but it is relatively hard to find the examples of best practices. Hardness in quantification of three tiers, complex interrelationship between economic and social considerations and still dominant position of economic values in environmental accounting could be given as reason why there is no reasonably good practice of TBL at the local governmental level. In this study, three dimensions of TBL for SUD will be scrutinised in accordance with the following rather simplified attributes:

- Economic: Net benefits of new development as to production and consumption of local products, creation of new jobs, increase in local tax base,
- Social: Accessibility to urban services and employment centres, provision of economical transportation services to low income groups,
- Environmental: Water, air, land and noise pollution created as a consequence of new development considering lifecycle process of its production.

**Land use and transportation models**

The history of urban models dated back to von Thünen's classical agricultural location model (Liu, 2009). By the improvements in computer technology and problem solving methodologies, at the beginning of the 50s, large number of urban models developed considering urban economics, transportation and demographic changes to explain evolving state of the urban form. Nearly all operational urban models have rooted theoretical and procedural approaches of this period. Linear analysis, operational research and simulation techniques were used to model dynamics of urban land-use, transportation and economics (Liu, 2009). Great expectations from urban models had worn assurance towards large scale examples with unsatisfactory explanatory outcomes of these models. As explained within this section, large urban models were criticised because of its focus on techniques existing rather than theoretical comprehension of dynamics of urban form (Liu, 2009). Ability of using disaggregate data into the urban models has led interest to novel modelling approaches, such as, choice models, activity based travel model, stochastic utility maximisation models and cellular automata, etc. After introduction of GIS tools, comprehension, computation, and visualisation capabilities of the models have reached to its contemporary level. Also increasing concern on sustainability has directed modelling endeavours to the most prominent determinants shaping cities, urban form and mobility pattern.

Relatively intensified experience of urban sprawl and externalities of this, e.g. traffic congestion, water and air pollution, deteriorating environmental assets, loss of community sense etc., in the United States have created wide interest on causes and remedies (avoidance strategies) for sprawl. Numerous researches have been examined various aspects of the relationship between land use and transportation. In general this relationship is studied in the literature of planning as built environment/urban form and travel behaviour/mobility characteristics relationship. These studies lead to emergence of "smart growth" program. American Planning Association (2002) defines it as 'the planning, design, development and revitalisation of cities, towns, suburbs and rural areas in order to create and promote social equity, a sense of place and community, and to preserve natural as well as cultural resources'. According to the this program, the planning and design principles of mixed-use zoning, infill development, brownfield development, transit-oriented development, jobs-housing balance, and strengthening of local commercial areas have been employed. This program also has given rise sceptical ideas related to the success of these policies because of not clearly defined association between land-use and transportation. In other words, these policies could be asserted as remedy for sprawl related problems, however, other factors out of urban form, such as, socio-economic and population dynamics, and complex structure of individual travel decision making process, etc., may be the main drivers of these problems.

In depth review made by Handy (Handy, 1996; Handy et al., 2005) has showed that the relationship between urban form, travel pattern and individual/household background is more complex than anticipated. In her study, Handy (1996) initially classifies studies undertaken to explain urban form and travel behaviour into five categories. These are simulation studies, aggregate analysis, disaggregate analysis, choice models and activity-based analyses. Simulation studies involve hypothetical testing of urban form according to the assumptions about development determinants. Aggregate analysis is employed to reveal comparative description of regions, sub-regions or cities as well as to infer relatively crude explanatory relationship between the elements of analysis. Disaggregate analysis uses individuals or households as unit of analysis and tries to associate individual characteristics and its relations to urban form and mobility demand. Behaviour patterns constituting overall decision pattern of the individuals are the main factor included into choice models. It scrutinises options open to individuals and probability of selection relevant alternative. This gives insights about the causal relationship between socio-economic characteristics and travel decisions. Activity based analysis takes daily human activities as analysis subject and tries to couple these activities with individual attributes of social and economic considerations. Studies of Handy (Handy, 1996; Handy et al., 2005) give invaluable knowledge about drivers of travel decisions. Some of the Interesting findings of these researches are as follows. The first problem discussed about built environment and travel pattern relationship is the direction of the association. While it is evident that transportation investments boost the development around highway corridors or for transit, near to the stops, the effect of urban form on travel behaviour is hardly asserted because of relatively low explanatory power of proposed models. It is possible to mention about the positive relationship between pedestrian-friendly urban/street layout and the trips made walking and cycling. Also, some studies show that density of the settlements and distance between uses is loosely related to the travel behaviour as opposing to prevalent belief. Empirical evidences shows that some socio-economic factors, e.g. having automobile, embracing walking or cycling as a daily activity and active social life, etc., affect travel behaviour more than urban form does. There are also evidences on changes in travel behaviour in accordance with the trip purposes. For example, home-work trips have high elasticity when travel costs, provision of public transportation options and high accessibility resulted from high population density and mixed land use are taken into account, but home to non-work and work to non-work trips generally have low sensitive to these factors. That is to say, people prefer to make these types of trips via automobile. When increasing proportion VKT or number of home to non-work and work to non-work trips in overall VKT and trips is considered, it points out the relationship between socio-economic attributes and mobility characteristics of the people (Handy, 1996; Handy et al., 2005).

In recent years, some sophisticated urban models integrating urban form and transportation related considerations have emerged. These models are used, in particular, in the US to simulate/forecast transit and land use change taking into account disaggregate data with different scales (household, neighbourhood or traffic analysis zone). Review made by Hunt et.al. (2005) compares six integrated urban models according to 'their 'operational' (the model must be used in one or more practical urban planning applications), 'comprehensive' (the model must include a -reasonably -complete range of spatial processes, notably land development, location choices by both households and businesses, and travel), and 'integrated' (meaning that feedback exists between the transport and urban activity systems, so that the short- and long-run interactions between transport network performance and land development/location choice behaviour are captured appropriately within the model)' qualities. After inspection of six frameworks, ITLUP, MEPLAN, TRANUS, MUSSA, NYMTC-LUM and UrbanSim, it is asserted that all frameworks have more or less differentiating aggregation level and unit of analysis, but they excessively aggregate spatial information. Yet, they do not include some endogenous processes, such as automobile ownership and demographic change processes, etc., uses static equilibrium assumption and rely heavily on classical four-stage transportation demand model. Despite these weaknesses, all of them has successfully embedded microeconomic evaluation module, integrates land-use and transportation coherently, and considers multimodal transportation network (Hunt et al., 2005).

As mentioned before, at the beginning of the 70s, after failure of the promising urban models in predicting future and shaping urban policies in the US, Lee (1973) drew four important conclusion related to the success of large-scale urban models. As summarised by Mercado and Paez (2005) “firstly, urban models should be transparent so that user could understand and use its capacities and weaknesses. Secondly, they must combine strong theoretical foundations, objective information and wisdom or judgment. Thirdly, planners should start with identifying a policy problem and not with a methodology that needs applying. Lastly, planners should build only very simple models because complicated models do not work” (Lee, 1973).

**Planning decision support systems considering sustainable urban development**

Decision support systems (DSS) are set of solution mechanisms that help all form of decision makers and related stakeholders to assess complex decision making processes and to solve problems faced by the help of ICT tools (Shim et al., 2002). The first ideas and projects about DSS dated to some 30 years ago. Particularly leap-frog developments of information technologies (ITs) have advanced use of these systems nearly all level of management problems (Keenan, 2006). Improvements in data storage and information processing capabilities of computer systems not only increase the volume of knowledge production from wide range of data but it also decrease the cost of utilisation of necessary hardware and software solutions.

Definition of DSS incorporates two main domains: policy; making decisions to solve respective problem, and technology; computational problem solving tools. Policy domain encompasses multi-faceted considerations, such as costs, benefits, time span, contingent effects of actions and stakeholder involvement. It also has become more complicated as the external factors, such as global inter-regional and local networks, novel technologies changing production and communication, changes in democracy framework, evolving social entities and demands, are taken into consideration. In today’s world, decision making process is more complex than ever because of number of unstructured/nonprogrammed or semi-structured problems (Gorry et al., 1971; Shim et al., 2002; Simon, 1960) faced. What the role of DSS in this domain is to give insights about the anticipated consequences of actions would be taken. It is the aim of DSS, without substituting decision maker, improving efficiency of the decisions made by human agents via considering all contingent factors related to the policies, optimising overall performance of them and minimising judgemental biases, not the efficiency with which decisions are being made (Turban, 1990).

Due to multi-dimensional geographical information need of urban planning profession, DSS has special element added to formal definition, which is called as spatial or planning DSS (PDSS) (Keenan, 2006). Among the planning professionals and governmental bodies, GIS is generally considered as DSS, because it embraces computational, analytical, problem solving and visualisation capabilities of classic DSS. However, as the definition and features of classic DSS compared with GIS tools, some authors emphases that GIS does not have adequate modelling components to be deemed as DSS (Armstrong et al., 1990; Keenan, 2006). The relationship between three systems, GIS, DSS and PDSS, is given in Table 1. It could be said that as GIS combine spatial data with problem solving models and have specialised decision making component, it could be considered as PDSS. Having explained previously, like other highly-political domains, planning encompasses different types of decision making approaches changing from setting to setting or even within public authority levels. Moreover, explanatory power of existing modelling tools sometimes do not let make generalisation to all urban settings because of unique qualities of them, or lack of necessary data, in some cases low quality data, make use of these models questionable. These issues force GIS developers to invent their own modelling tools as add-on instead of software-embedded ones or, simply, planners settle for ready-made analysis and planning tools provided by software.

Table 1. Relationship between GIS, DSS and PDSS, derived from Keenan (2006, p.16)

| GIS | DSS | PDSS |
|---|---|---|
| Concerned with spatial data | Can be in any problem domain | In problem domain with spatial component |
| General purpose tool | Specialised software | Specialised software |
| Spatial database | Database | Database with spatial component |
| General spatial data handling models | Specific decision models | Specific decision models making use of general spatial and planning data models |

GIS uses relatively higher resolution geographic data in forms of tabular, vector and raster. These constitute multilayered spatial aspect of analysed setting and with the help of analysis and modelling tools in GIS softwares, status of urban areas and future scenarios about economic, social and environmental considerations could be easily evaluated and visualised (Ascough et al., 2002). Review made by Malczewski (2006) shows that major application areas using GIS as PDSS were environmental planning/ecology and management, transportation, urban and regional planning, waste management, hydrology and water resource, agriculture, and forestry from 1990 to 2004. While decision criteria utilised in these application are land suitability, resource allocation, scenario evaluation, impact assessment, and site selection, combination/decision support rules used in these studies were multi-criteria decision aid methods, such as, weighted summation, ideal or reference point analysis, Analytical Hierarchy Process, outranking methods for alternatives, linear-integer programming, heuristic search/genetic algorithms, and goal programming (Malczewski, 2006).

The inherent power of GIS tools lays its expandable and user oriented software architecture. This feature of GIS could be exploited to conversion of GIS to PDSS. One of the main qualities of PDSS is that by adding aforementioned DSS mechanism to it, it could be used as integrated PDSS. By this, alternative future plans and urban development policies that demands decision making endeavour on the substantial characteristic of any urban setting, land use, environment, transportation and infrastructure, could be considered simultaneously. This, at the ultimate level, provides integrated planning actions and efficient SUD policy development. At this stage the most important struggle of how features of GIS could be improved to enable well-developed and operable PDSS come to the fore. GIS has already had some necessary capabilities that close it to classical DSS, for example, database structure and management, adaptation of necessary information processing algorithms, visualisation and distribution of knowledge for interested parties. If GIS could be improved at the software level, that is to say, as its expandable and user oriented architecture is exploited according to the designated PDSS framework, it could be effectively employed when producing integrated planning action sand efficient SUD policies. It points out that, initially, more effort should be devoted to enhancement of modelling capabilities of GIS and to addition of user interfaces which could be used for scenario development and reprogramming of the embedded model parameters.

**An integrated land use and transportation index**

The main reason behind the land-use and transportation integration is that even it is expected that decision making initiative and process practiced on these interrelated two urban-forming entities should be coupled well, but in practice, planning of these domains is generally made by different local or governmental institution. For example, transportation planning problems and models are assigned to transportation engineers or economists/econometrists, whereas land-use planning activities are conducted by urban planner, urban designers or architects. Transportation models used generally employ regional, neighbourhood or designated analysis zone as unit of analysis in a form of input matrices, and in general they are aspatial. Urban planners use these model outputs as input in their planning endeavours with limited information about determinants and assumptions used in the model. This relatively separated approach might cause efficiency and dissonance problems in the urban settings. SUD problems experienced and inherent interdependence between land-use and transportation force planners and policy makers to pursue an integrated framework for locally adoptable policies.

Spatial indexing has been used for various studies for various purposes. Widespread use of GIS by different disciplines has helped emergence of many indexing studies in the literature. Among all environmental management discipline is the most fruitful area that uses spatial indexing with GIS tools. These studies ordinarily focus on risk assessment of environmental assets (water, forest, and endangered habitats), catastrophes, pollution and suitability index for habitat. Also, in geography and urban planning disciplines, description of urban issues with spatial indexing method has been employed by various researches. In these studies, GIS tools have been used for describing and visualising spatial segregation, accessibility to urban services or for simplification/categorisation of geographic features such as, slope, relative distance to specified point(s). Strength of indexing is related to the comparatively simplified and easily understandable representation of geographic qualities. However it is also constitutes main weakness of this approach, overly generalised/aggregated representation of the features and loss of important details. In order to overcome the weaknesses of indexing method, some important points should be scrutinised attentively. These are:

- Unit of analysis should be selected according to the level/scale of the information at hand, and expected intermediate-final outcome of the study,
- Selection of categories or ordinal intervals defining indices should be determined not to lose necessary information due to rounding operations,
- The most critical part, assignment of relative weight of information layer should be theoretically sound and consistent,

- For enhance operability of the model, information layers and user interfaces, if any, should be designed to provide some qualities, e.g. transparency, easily modifiability, modularity for incorporation or deduction of other information layers or interfaces, ability to show outcomes with different information sensitivities, etc.

In this study, land-use and transportation problems of Gold Coast, Australia, will be embraced according to SUD framework. For this, SUD considerations will be translated into relevant indicators/variables for creation of spatial index. These indicators would be grouped into two as to their spatial characteristics, spatial and aspatial (attributes) and into three according to the SUD problem domains as urban form, transportation and socio-economic attributes. The latter indicator group will encompass land-use, population density, job-housing ratio, employment centres, slope, vegetation, transportation network with the attributes of volume, capacity, level of service (LOS), average speed, grade and pavement, mode choice, automobile ownership, vehicle kilometre travelled (VKT), vehicle attributes (fuel type, age, engine type, etc.), accident and fatality statistics/locations, and population attributes (age, gender, occupation, education, income). Each indicator or composite of relevant indicators will be processed as different data layer. In this study, the grid shaped lattice of urban form layers with 25mx25m dimensions will be used as unit of analysis. First reason for selection of grid-unit-of-analysis is computational simplicity in terms of computer processing time. Otherwise processing of large number of input layers will demand special computer equipments and limit the use of the model, in particular in changing model parameters to rerun the model. Selected dimensions of the grid give relatively fine detailed picture of the urban setting (625 sqm of grid area). It also may help researchers or policy makers to identify problematic or well-performing areas in the urban setting easily via visual inspection of categorical accumulations.

Other main component of the model, transportation network, will be used as original details, without making any geographic modification or rectification. Relationship between urban form grids and transportation network will be supplied with calculation of Cartesian distance of the grid centroid to the closest network segment. Socio-economic qualities of the selected sites will processed with urban form and transportation layers to constitute inferred layers showing local relationship between these indicators. According to the availability and level of these data, pertinent statistical inference techniques will be used for formation –aggregation or disaggregation of these layers.

After selection and collection of relevant data, by the help of designated inference tools, raw GIS layers will be converted into grid layers. This tool will also be used for conversion of aspatial data (socio-economic characteristics) to spatial data. It will be followed by modelling phase of the characteristics of urban setting. Spatial and statistical analysis module will help to reveal relationship between urban form, transportation and socio-economic characteristics. It will produce and store parameters to be used for evaluating the effects of the future scenarios. After spacial and statistical analysis phase, indexing module will produce sustainability index set. This index set will include accessibility to public transport, total energy used, pollution created, local government urban service provision costs and increased tax base, local employment and economy improvements, and probable traffic congestion areas. Each index layer in the index set will reflect different aspects of urban setting. Values at the each layer of index set will be processed with the assigned weights to produce composite sustainability index. Assemblage of index set will be made via designated integration tool. Composite sustainability index will show how proposed urban development will produce future urban form according to sustainability perspective. Last module, evaluation and policy will redefine composite index as to economic, social and environmental characteristics (TBL indexes) for the areas where indexing experience shows sustainability problem. It will also combine policy options and future urban development scenarios which will be used as model input at the next iteration to assess probable effects of policies. These four modules constitute overall PDSS. By interfaces in the indexing module, decision makers could change the relative weights of composite index layers and also could see sensitivities of sustainability index set which gives some ideas about problematic attributes of urban setting. Procedure of the model is summarised in Figure 1 below.

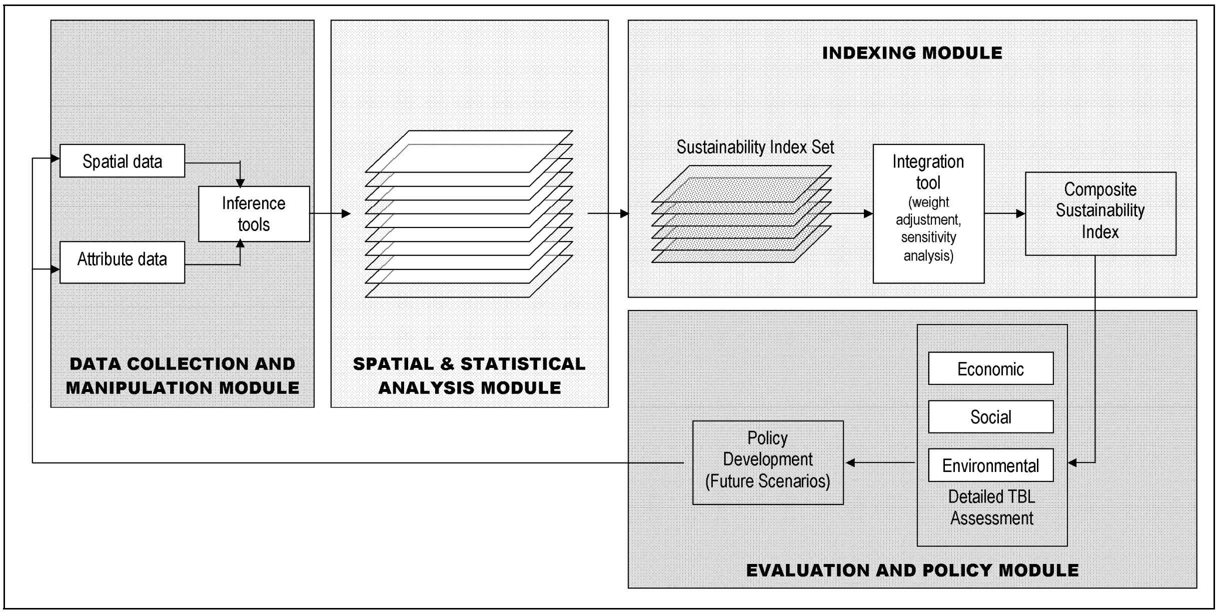


Figure 1. Components and procedures of integrated land use and transportation model

**Conclusion**

In the literature, there are a number of studies that examine environmental impacts of transportation activities or land use and population density (Hunt et al., 2005; Smith et al., 1995; Waddell, 2002), but there are only a handful of studies taking dynamic relationship among urban land use, transportation, environment and society into account (Cahill, 2002; Keller, 2004; Yu, 2004). Even though, this research examines applicability of operational, comprehensive and integrated land-use and transportation indexing model, it also helps to make inferences about environmental and social dimensions of overall sustainability framework. The use of indexing method provides unambiguous representation of relationships forming urban form and problem areas of the urban setting where necessary policies could be tested and employed via policy module of the model. Modularity of the model helps to make addition or modification of the modules, if necessary. Additionally it incorporates SUD framework according to TBL approach and might deemed as good example of similar approaches after its implementation. Thus, the proposed model employs a holistic view to urban dynamics and is not only an invaluable environmental impact assessment tool but is a PDSS for decision makers. When considered with growing population, urban problems and changing climate, this model has an immense potential to aid involved parties in formalisation of SUD policies.

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